IMAGING OF MAGNETIC DW INJECTION PROCESSED IN PATTERNED $Ni_{80}Fe_{20}$ STRUCTURES

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Magnetization reversal in patterned ferromagnetic nanowires usually occurs via domain wall (DW) nucleation and propagation from one end (or both ends) of the wire [1] which can be significantly reduced by a large, magnetically soft pad on one of the wire ends [2,3]. These 'nucleation pads' reverse at lower fields than an isolated nanowire and introduce a DW to the wire from the wire end attached to the pad. Once a critical 'injection' field is reached, the DW sweeps through the wire, reversing its magnetization. Nucleation pads are frequently used as part of nanowire devices and experimental structures. Magnetic-field-driven shift register memory can include an injection pad to write data [4] while those attached to nanowire spiral turn sensors act as both a source and sink of domain walls [5] Both of these devices use two-dimensional wire circuits and therefore require the use of orthogonal in-plane magnetic fields to drive domain walls through wires of different orientations. These bi-axial fields can significantly alter the fields at which DW injection occurs and control the number of different injection modes.

We have used magnetic transmission soft X-ray microscopy (M-TXM) [6] providing 25nm spatial resolution to image the evolution of magnetization configurations in patterned 24nm thick $Ni_{80}Fe_{20}$ rectangular nucleation pads and attached wires during DW injection. The structures consisted of 2 μm × 3 μm nucleation pads with wires of width 200 nm, 300 nm or 500 nm attached Comparing the magnetic configuration of the injection pads with micromagnetic models, we find that the relative orientation of closure domains in the remanent magnetization configuration of injection pads determines the reversal pathway that follows, although this is further affected by applied transverse fields.

Micromagnetic simulations were performed using a hybrid finite element/boundary element code [7]. The magnetic elements were designed with 20 nm thickness and discretized into a mesh of tetrahedral elements with a maximum cell size of 20 nm. Material properties for bulk permalloy were used, i.e. exchange stiffness $A = 1.3\times10^{-11}$ J/m, saturation magnetization M_S = 800 kA/m, magneto-crystaline anisotropy K = 0 Jm^{-3}, damping constant $\alpha = 0.01$. A linearly increasing magnetic field (1 Oe/ns) was applied parallel to the wire long axis to simulate switching fields. The dimensions of the simulated structures mimicked the essential features of the experimental structures, although edge roughness was neglected from the model.

The remanent magnetization state of the pad with no transverse field consists of a uniform magnetization aligned with the wire axis, with closure domains at the edges facing and joining the wire. When $H_y = 0$ Oe and $H_x = 20$ Oe, the magnetization state of the pad buckles, forming eight domains, half of which have magnetizations rotated away from the x-axis. As H_x is increased, the rotation of the domains become larger and the non-rotated domains shrink A transverse field applied in addition to the axial field exhibits a more complex modes of magnetization reversal in the pad (Fig. 1)

We understand the pathway of pad magnetization more generally by using micromagnetic simulations. Two initial configurations are shown in Fig. 2 with the closure domain on the left-hand edge of the pad either parallel or anti-parallel to both closure domains on the right-hand edges of the pad. As H_x is increased to inject a domain wall, the pad magnetization states changed to vortex states, as observed by M-TXM. At higher fields, the magnetization of the modelled pad became single-domain, although closure domains remained at fields up to H_x = 90 Oe. This supports the suggestion that experimentally observed multi-modal injection is due to the magnetization state of the pad [8].

In summary, the relative orientation of closure domains in the pads determines the magnetization reversal pathway under an axial field. However, the addition of transverse fields can alter these and lead to the pads undergoing reversal under lower axial fields. Our observations have wider implications for experiments and devices using patterned magnetic wires.

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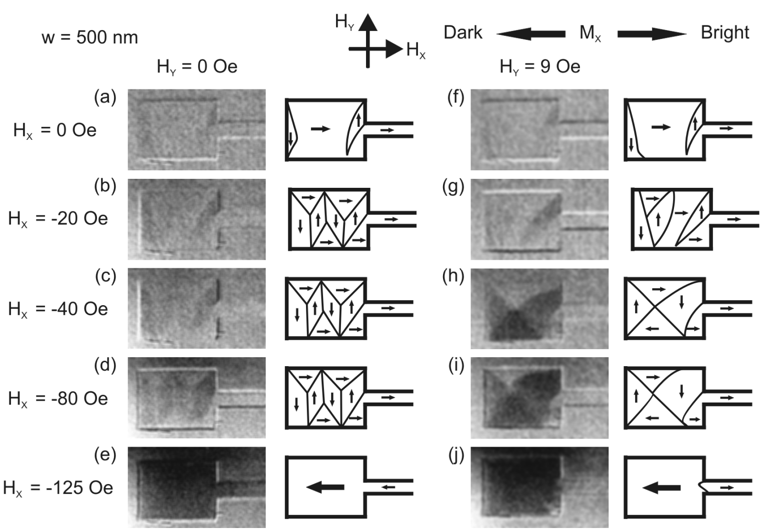

Fig. 1: M-TXM images showing the magnetization state of a 3 µm x 2 µm nucleation pad with a wire of width, w, 500 nm. H_x and H_y are applied as indicated. The schematics are a guide to aid interpretation of the images. The images were obtained by using 707 eV photons and by comparing raw images for the fields shown with one of saturation under H_x = 500

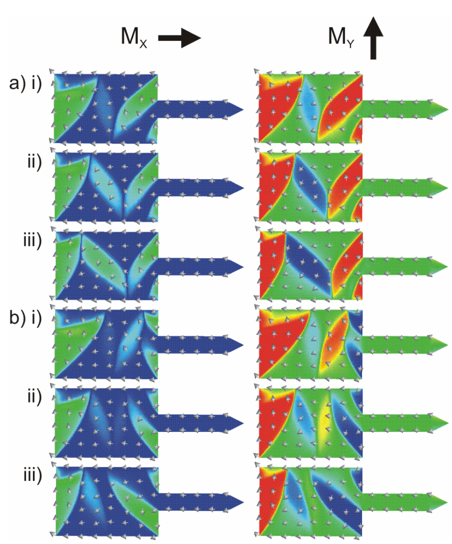

Fig. 2: Micromagnetic simulations of a 2 µm x 3 µm x 20 nm Permalloy pad attached to a 500 nm wide wire. The closure domains on the right-hand side of the pad are (a) parallel or (b) anti-parallel to the left-hand closure domain. In each case, H_x = 15 Oe and H_y = (i) 10 Oe, (ii) 0 Oe and (iii) -10 Oe.